[redacted] STAT

April 4, 1967

STAT [redacted]
P. O. Box 8031
Southwest Station
Washington, D. C. 20024

STAT Dear [redacted]

Enclosed are three copies of the Quarterly Status Report No. 8 for [redacted], covering the period July 1, 1966 to March 30, 1967. STAT

Very truly yours,

[redacted] STAT

REH/es
STAT cc: [redacted], Contracting Officer
Research Administration [redacted] STAT

STAT

[redacted]

Quarterly Status Report No. 8

July 1, 1966 to March 30, 1967

Aspheric Optical Systems

Review of Projection Screens [redacted]

STAT

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[redacted]

Summary

This report recommends terminating a study on the use of aspheric surfaces in projection lenses. Several lens designs with aspheric surfaces were designed on three modern powerful optimizing programs. The designs were always compared with similar all spherical designs. The aspheric designs were slightly superior to the all spherical designs but not enough so to justify the extra expense of aspherical surfaces. It is recognized that the automatic design programs may have missed promising regions of solution. By recommending concluding the direct assault we are merely saying our present progress does not justify continuing. Other designers should by all means continue to design aspheric systems if they believe they have the germ of an idea which we may have missed.

Final Status Report on Aspheric Surfaces

This study was undertaken to evaluate the usefulness of using aspheric surfaces in refracting lens systems. Aspheric surfaces have been used for many years in astronomical instruments but they have not been used in refracting objectives. There has always been a feeling that aspherics should be avoided because of the increased cost. It was considered appropriate now that large computers are available, to make a theoretical study of refracting lenses with aspheric surfaces. If the studies could show exciting new possibilities it would certainly lend impetus to the development of practical methods for making aspheric surfaces.

This study considered the use of aspheric surfaces in two basic types of well-known photographic lenses. In order to evaluate the aspheric designs a considerable amount of time was spent designing optimum all spherical lenses of same basic types.

The Triplet Study

The first lens studied was a Triplet objective. The results of this study were reported to the Tokyo meeting of the International Commission on Optics[1] and in Quarterly Status Report #5. A triplet objective with four aspherics was compared with two other triplets and two four element lenses. The aspheric lens appeared to offer very little advantage other than size. It was possible to design a much smaller and compact triplet using aspheric surfaces. This appeared to offer very little advantage in small size lenses. It might however be an appreciable advantage in lenses of large diameter where weight and glass cost is appreciable.

This design study made us acutely aware of the complexity of the theoretical problem and the magnitude of the computing involved in making a definite study. The original study was made using ORDEALS on an I.B.M. 7074[2]. We soon realized that the problem was beyond this machine. The study was then repeated using a 7094 at White Sands using the Automatic design program of [redacted] This program goes about corrected lenses in quite a different way, and it appeared to turn out some fairly remarkable designs. The best design was also reported in the 5th Status Report. The aberration curves were generally flatter but upon close examination it was found that the diffraction image quality would be poor. The [redacted] program showed clearly that one had to be very careful about introducing high order aspheric deformations. The automatic design programs would balance out the high order aberrations quite effectively but the residual aberrations

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became very large. It was clear that with an extensive design program one could probably arrive at a triplet design with aspheric surfaces which was better than the design shown in the Tokyo paper, but the improvement still did not seem to justify the use of four aspherics.

Automatic Design Programs

The experience with the ORDEALS program and [redacted] pro- 25X1
gram readily convinced us of the need of excellent large scale design problems in order to truly cope with the design of lenses with several aspheric surfaces. The Triplet study was disappointing in showing limited advantage in using aspheric surfaces, but it also showed us many deficiencies in our design techniques. Before taking on more complicated designs we decided to spend the time to make several changes in our program. We therefore spent a great deal of time modifying the design program called FLAIR. One of the main advantages of FLAIR was that it was able to correct the wavefront errors. This enabled us to penalize designs that tended to have large oscillations in aberrations. The FLAIR program was eventually made to operate on several large machines so that we had access to adequate computing power.

The Double Gauss Projection Lens

The final design study was made on an 10 cm focal length f/2.1 projection lens of the double Gauss type. The design

study was carried out by [redacted] using FLAIR on the 25X1
25X1 Xerox machine. [redacted] completed most of this study prior to the end of this contract but the study will be completed as part of his thesis. We plan to submit the results of our entire study in a published paper. This will however not be ready until after contract is complete.

The first step was to design a well corrected projection lens. The design data for this lens is included in Table 1. The aberration curves are shown in Fig. 1.

The second lens used two aspheric surfaces on the two outside surfaces. Fig. 2 shows the aberration curves for this lens. The lens itself changed very slightly from the all spherical design. The difference lies mainly in the use of the aspheric terms.

The third lens used two aspheric surfaces on the two innermost surfaces. The aberration curves for this lens are shown in Fig. 3.

25X1 [redacted] is also designing a system with a single aspheric located in the stop.

The overall performance of the first three designs is summarized in Table II. The resolution limits for the lenses are given. The resolution limit was determined by noting the frequency at which the modulation dropped to a value of 0.1.

There is no doubt that the aspheric surfaces do help the original design. It would however again be difficult to justify the use of aspheric surfaces for this slight gain. A manufacturer would probably elect to add extra elements or turn the cemented surfaces into air spaces.

Conclusion

The design efforts have shown that the liberal use of aspheric surfaces in refracting objectives do not offer spectacular improvement. We have shown that any given objective may be improved by adding one or more aspheric surfaces. As a practical problem however one will probably not be able to justify the use of aspheric surfaces in preference to using air spaces or adding an extra element or two.

We feel compelled to comment on the conclusions we have reached in this study. We seem to be contradicting the wide experience of optical designers. It would be almost universally accepted that aspheric surfaces are extremely useful and that their high cost is the primary deterrent in their being used extensively. There are several points to remember. We have been primary interested in refracting objectives used as camera or projection lenses. The lenses we have considered are of short focal length. By the time one has added lenses to obtain proper color correction and Petzval curvature one has sufficient degrees of freedom to correct the lenses with all spherical surfaces. Aspheric surfaces come into their own in objectives using basically minor components. It is difficult to design mirror systems with closely adjacent aberration balancing surfaces. Aspheric surfaces then are essential for basic aberration correction.

Aspheric surfaces become feasible again in long focal length refracting systems where the cost of the elements is high. Then it is worthwhile to aspherize the surface in order to gain full use of the elements.

We do not particularly like to shed discouragement on the use of aspheric surfaces at this particular time. We found ourselves using powerful new tools for optical design without a great deal of experience in how to do it. We tended to use our modern programs to design lenses by the conventional methods. We usually start from all spherical systems and then add aspheric deformations. We provide conventional starting places, and conceivably there are other regions of solution which we did not find. In the case of the Triplet we believe that this is quite unlikely. The triplet with aspherics is actually quite different in appearance from the aspherical triplet. Even though we started from a spherical design the automatic program made large changes and did not remain in a local minimum. It is also interesting to note that [redacted] program also converged to essentially the same region of solution. The double Gauss type is a different story. There are so many alternate designs for this lens that we would be presumptuous to assume we found the best solutions in the three trials made.

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Summary

This study has indicated that the liberal use of aspheric surfaces does not appear to offer appreciable advantages in the design and building of refractive projection lenses. We therefore do not recommend further direct assault on the problem at this time. It is our hope that this does not discourage other designers from using aspheric designs. We believe, through the process of continued design development using large scale computing machines, that eventually meaningful aspheric surfaces will find their way into systems of the future.

SURFACE	CURVATURE	THICKNESS	GLASS
1	0.1999	0.626	SK 16
2	0.0790	0.010	AIR
3	0.3106	1.020	BAFN 10
4	0.0261	0.171	SF 2
5	0.4377	1.394	AIR
6	0.0000	1.427	AIR
7	-0.3843	0.160	F 2
8	0.0094	0.901	BAFN 10
9	-0.2866	0.008	AIR
10	-0.0041	0.540	SK 16
11	-0.1523	6.559	AIR

OBJECT DISTANCE	204.46
FOCAL LENGTH	9.9328
BACK FOCAL LENGTH	6.559

Table 1. The specifications for best all spherical design.

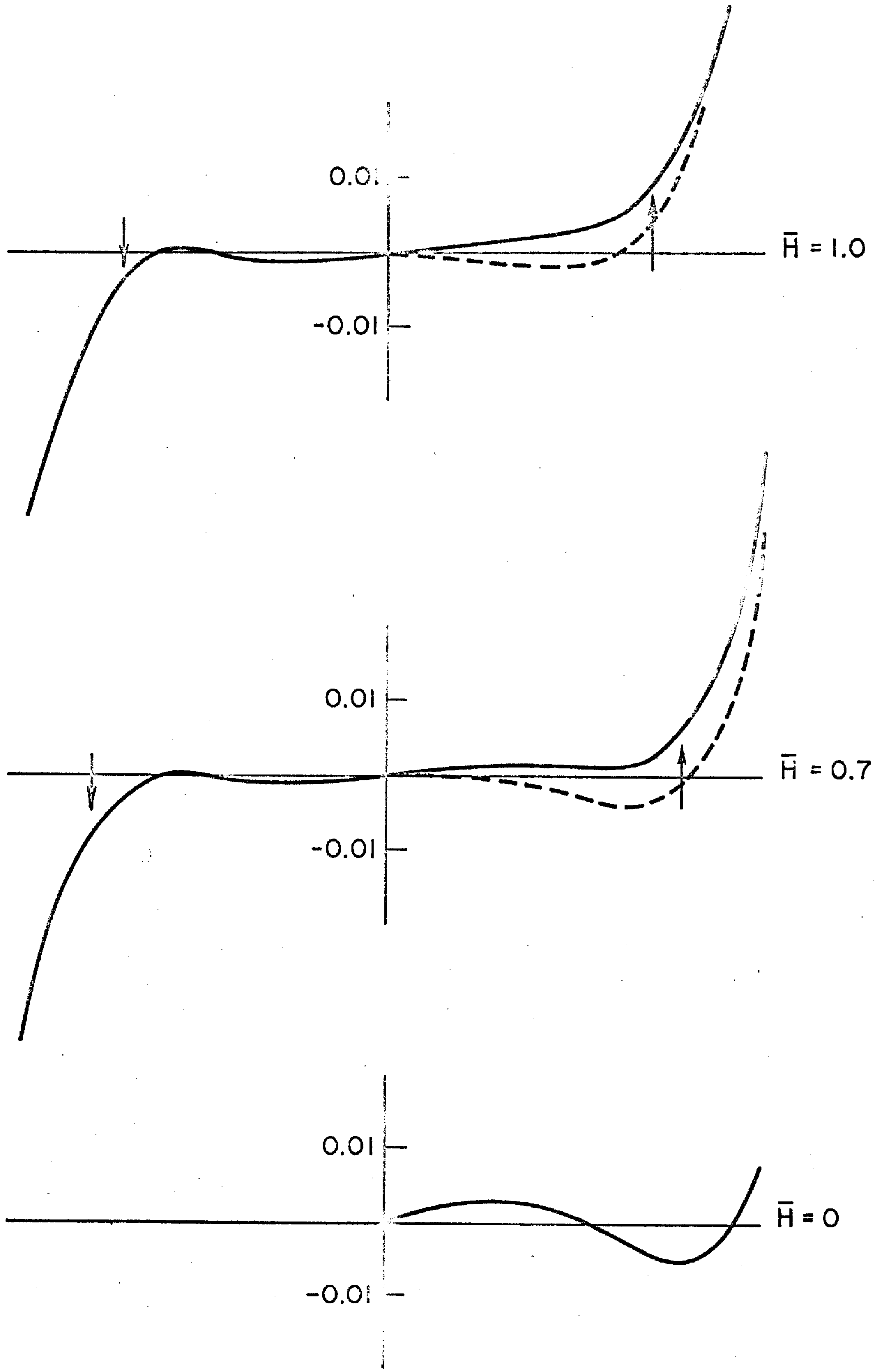
	Resolution Limit (lines/mm)		
Field Height	Lens A	Lens B	Lens C
0.0	20	>50	>>50
0.7	20	27	29
1.0	18	50	29

LENS A BEST SPHERICAL LENS

LENS B ASPHERICS ON OUTSIDE SURFACES ℓ/mm

Lens C ASPHERICS ON INSIDE SURFACES

Table 2. Summary of cutoff resolution for three double Gauss lenses. The lenses had the following constants $f' = 10$ cm, f/number = 2.1, total field 42°, magnification -0.05.


0.01
-0.01
$\bar{H}$ = 1.0
0.01
-0.01
$\bar{H}$ = 0.7
0.01
-0.01
$\bar{H}$ = 0

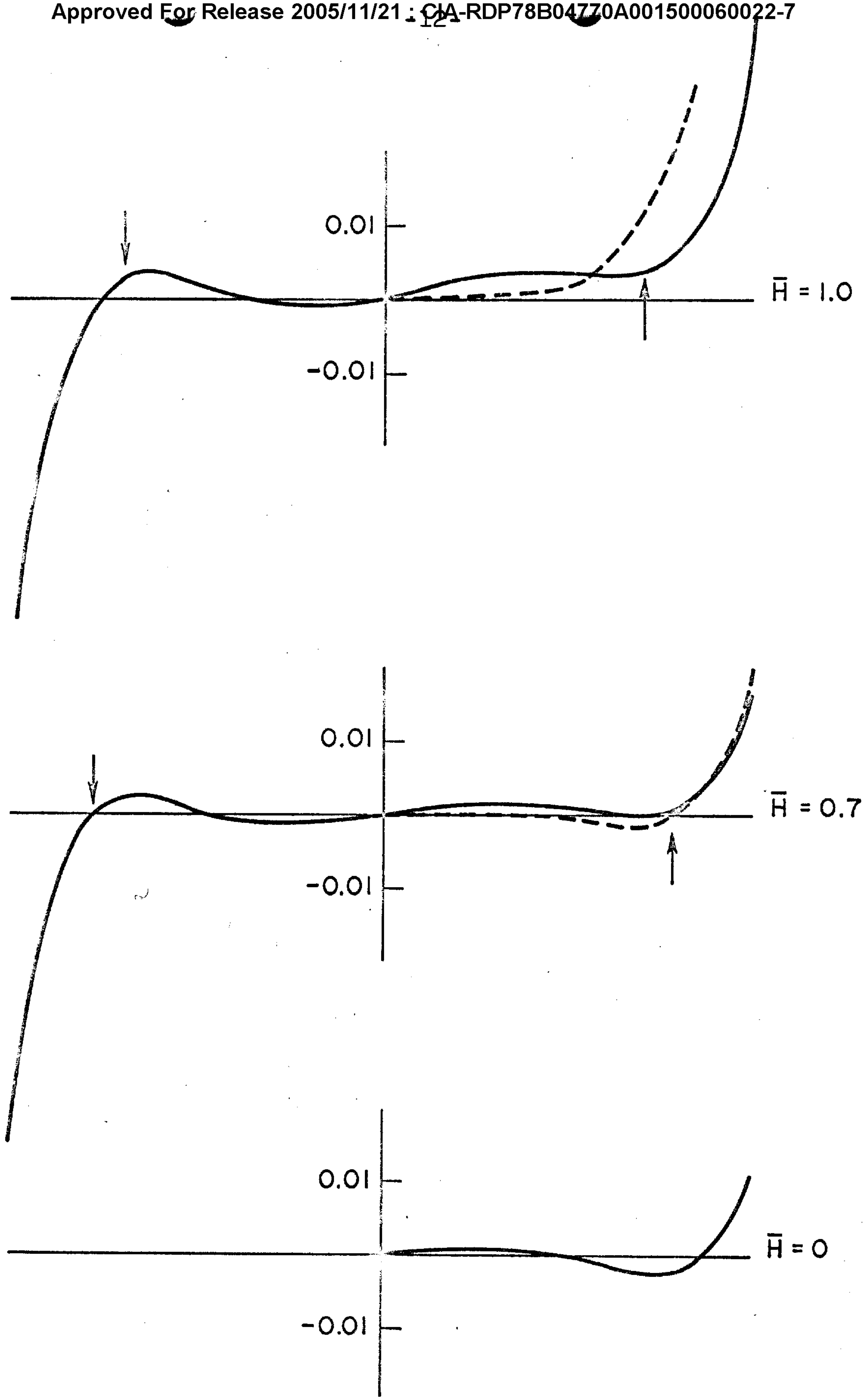


Fig. 2

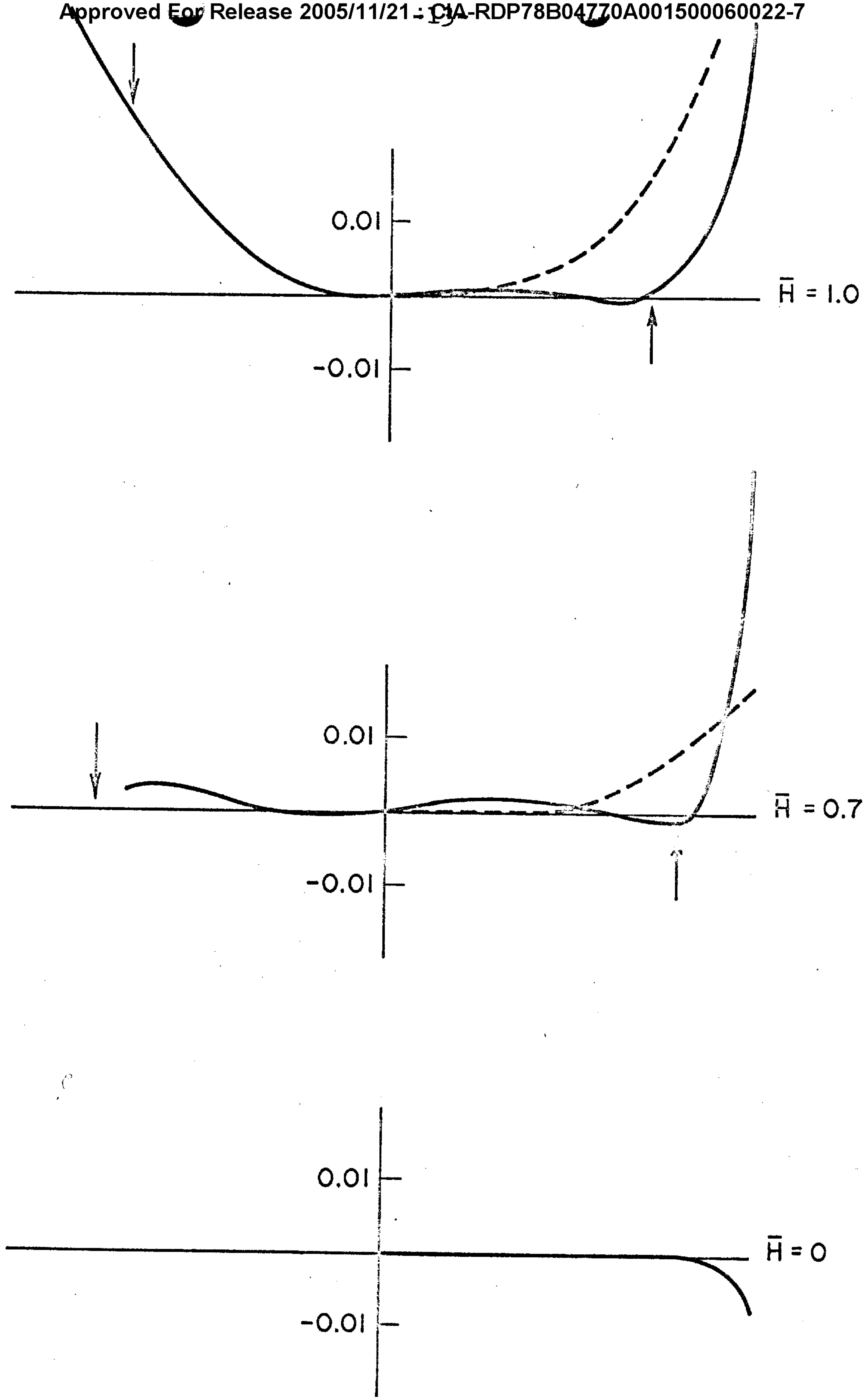


Fig. 3

Captions For Figures

Figure 1. The aberration curves for the best all spherical projection lens. The solid lines refer to the meridional rays. The dotted lines refer to the skew fan. The horizontal axis represent relative positions in the aperature. The vertical scale is the transverse aberration.

Figure 2. The aberration curves for the projection lens with aspherics on the outside surface.

Figure 3. The aberration curves for the projection lens with aspherics on the inside surfaces.

References

1. Jap. J. Appl. Physics, Vol. 4 , Supplement 1, p. 60, 1965

2. ORDEALS Manual submitted with Quarterly Status Report #5.

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Review Progress on Projection Screens

STAT The [redacted] group have made a careful and interesting study of scattering and particular problem of rear view screens. They showed us a few samples of screens they had made. These screens showed promise but really they were in too early a state of development to evaluate. The usefulness of these screens will depend on uniformity of scattering and practical methods of manufacture.

STAT [redacted] should be asked now to concentrate on the producing of a few samples of screens. The present support could be continued to allow [redacted] to make these samples STAT and describe their results.

Research of this type can get to be endless. Government support should be enough to help the [redacted] group STAT convince their management that this technique has merit. If the management cannot be convinced after a point the project should probably be dropped. It is my impression that the program is nearing that stage now. The remaining time should be spent in preparing samples to present to the outside world to see if it generates any interest. If it doesn't then it is doubtful if support should continue. Fairly wide spread support from the general public will be necessary before screens of this type will be put into production.